UCRL-JC-124505 Abs

Further development of shallow-relief gratings for beam diagnostics applications on NIF

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The NIF baseline design includes beam sampling gratings that diffract, in transmission, a small fraction of third-harmonic light into calorimeters for beam energy diagnostics. Original specifications call for full-aperture plane gratings of about 2 micron period, to diffract 0.3+/- 0.1% of this light at an angle of about 10^{o} to a curved folding mirror and then to the calorimeter. In earlier work[1] we demonstrated 15 cm. diameter plane gratings wet-etched into bulk fused silica that met diffraction efficiency and laser damage threshold requirements. These gratings were etched using a buffered hydrogen solution to a groove depth of about 30 nm through a photoresist mask created using large-aperture interference lithography.

During the course of this work it became known that a standard surface polish is inadequate for further processing to make gratings by wet etching. The wet etching step exacerbates subsurface damage cracks, leading to large scatter loss and increased surface roughness. A polish process containing intermediate etching steps (a more expensive chemical/mechanical polish, or CMP) process, which minimizes subsurface damage, is required. Also, bulk etching puts the optic at risk, since parts that don't meet specifications require repolishing at considerable expense. We are investigating the feasibility of low-efficiency gratings made from a very thin film of material deposited on the SiO_2 substrate. These gratings can be removed by chemistries that do not affect the bulk material, and a standard polish of the optic is adequate, and gratings can be stripped without repolishing the substrate.

There are two basic processes that can be utilized to make thin-film gratings; 1) deposition/lithography/etching; and 2) lithography/deposition/liftoff. The first is similar to the etching of gratings into the bulk substrate, except that a high-laser damage film is deposited by evaporation first, lithography to make the grating mask follows, and the wet etching is done with a chemical that dissolves the exposed thin film without affecting the bulk SiO_2 substrate. The latter process involves creating a high aspect-ratio grating mask in photoresist on the bare substrate, evaporating a thin film coating over it such that essentially no material attaches to the mask sidewalls, and then removing the photoresist, leaving behind a thin film grating where the substrate was not covered by the resist mask. This process requires no etching step, but does require the ability to make a very high aspect ratio photoresist mask during the lithography step to ensure clean liftoff of the resist. In this paper we discuss suitable candidate materials for thin film gratings, describe the manufacturing process and report laser damage and efficiency results of plane gratings made from MgO and MgF_2 films on SiO_2.

To provide more space in the compact geometry of the target chamber, it is advantageous to build additional focusing power to the grating and eliminate the need for a large-aperture folding mirror. The NIF baseline design has been changed to stipulate a grating which focuses the transmitted diffracted beam 15^{o} from normal to a spot about 1.1 m away. This requires a variable period across the grating surface from approximately 0.8 to 3 μm. We present theoretical results that show that for shallow groove depths, the efficiency is independent of the period over the range of interest, and show preliminary results of diffraction efficiency measurements of 15 cm. diameter gratings made with focusing power.

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[1] J.A. Britten, R.D. Boyd, M.D. Perry , B.W. Shore and I.M. Thomas, First Annual Intl. Conf. on Solid-State Lasers for Application to Inertial Confinement Fusion, M. Andre and H.T. Powell, eds., SPIE Vol. 2633, 121-128 (1995)

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

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Preference is for poster presentation